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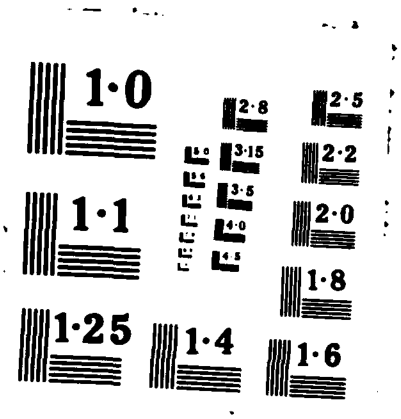
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Expert System Prototype for False Event Discrimination

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Lt. Wayne Chunn was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses a prototype expert system for event discrimination. We wanted to determine whether applying an expert system to handle and interpret satellite telemetry data is feasible and worthwhile, considering the large amount, the variety, and the complicated nature of the data. The system makes decisions regarding the validity of events by using a knowledge base acquired from satellite systems experts. Decisions are influenced by the health of the satellite, the sensors and the data processing, by knowledge of the phenomenology, by physical phenomena affecting the sensors

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20. ABSTRACT (Continued)

and by other potential sources of erroneous information. We conclude that the expert system is an apt vehicle for growth of systems knowledge, for quick decision making, and for giving explanations of the reasoning and of the derived information base to ensure user confidence.

CONTENTS

FIGURES

1. INTRODUCTION

The False Event Elimination project applied Expert System techniques to improve discrimination between true and false detections made by a mission data processor. The goal was to build a prototype system that demonstrated good discrimination performance against recorded mission data, and provided clear specification of the factors considered in each decision.

Two computer programs were developed in the project. A demonstration decision-making system was built consisting of an expert system coupled to pattern recognition and correlation programs. A mission display program was also created in order that the expert system developers could see the data normally available to the human operators. This report describes the expert system that was implemented in the demonstration.

Section 2 describes the overall expert system approach, why it was chosen, and an evaluation of the system as it currently operates. Section 3 describes the rule-based knowledge in the system, which is our functional model of the operator's decision process. This section includes the input features provided to the expert system and the logic involved in making a decision about the event. Finally, Section 4 explains many of the details of the implementation of the expert system program.

It is recognized that the rule base presented here has flaws, however the intent was to model a reasonable amount of the knowledge to provide a baseline system for demonstration of feasibility and capability. It will be a test of the expert system approach to have other experts improve upon what we have done.

2. DESCRIPTION OF THE DEMONSTRATION SYSTEM

2.1. OVERVIEW

In this project we are developing an "intelligent" algorithm to analyze remotely sensed data collected by satellite. It is an example of adding an expert system to an existing signal processing program.

At present, a signal processing computer analyzes time-varying patterns in the collected data in order to infer that actual changes or "events" have occurred in the real world. In addition, the computer displays a filtered version of the data superimposed upon a map. When the computer finds a specified pattern, it notifies the display operator that a potential event has been found. The operator judges whether the event is true or false, i.e. whether or not the pattern corresponds to an actual event, by examining both the pattern and its context within the display. In almost every case the operator correctly identifies true events and eliminates false events that were not rejected by the computer.

The goal of the project is to reduce the number of false events reported and ultimately to create an autonomous system. The first stage is to provide an "intelligent assistant" to unseasoned display operators by providing expertise usually only available from systems engineers and analysts.

This report will describe an expert system which is being built to discriminate selected patterns, "true events", from many other signals, such as noise and other unwanted sources. The system must handle information about sensors, such as their operation and failure modes, about natural phenomena, such as reflections off ice-capped mountains, and about the particular pattern which must be distinguished from noise and other signal sources.

Figure 1 depicts the organization of the expert system. The system begins with initialization, the data case is selected, and the tables are read. The bold arrows in the diagram show the main course through the system. The elements composing each of the blocks will be explained in the following sections.

2.2. KNOWLEDGE BASE

An expert system was chosen over a standard programming approach for a few reasons: the ease in adding knowledge and in modifying existing knowledge without major reprogramming, the interactive capabilities for explanation, verification, and debugging, and the independence of the knowledge base from the inference system (changing or replacing either will not affect the other).

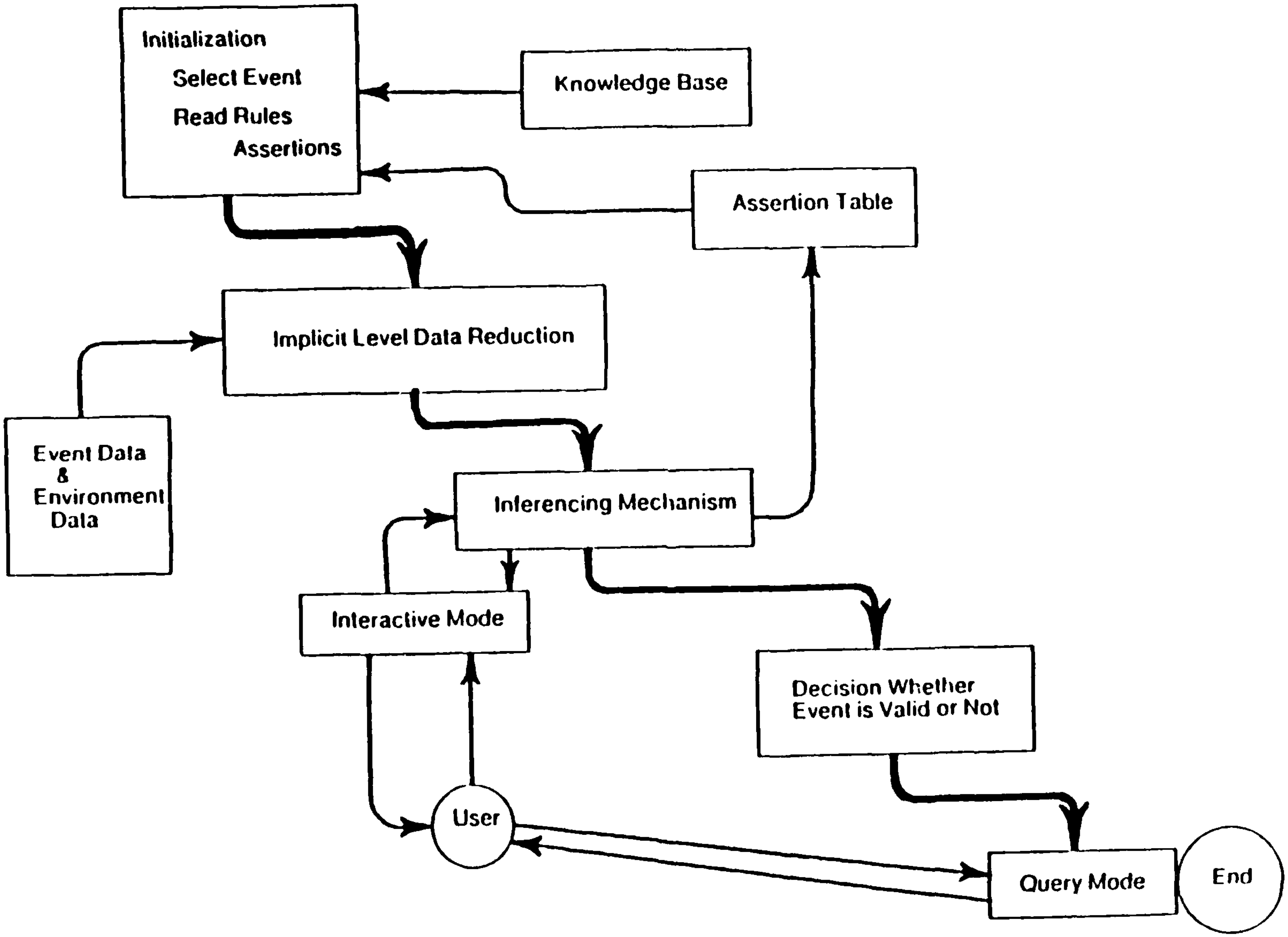

Figure 1. Overview of Expert System Organization

The knowledge base is an independent table of production rules that encapsulate the relevant knowledge of satellite systems engineers and data processing analysts as to the causes of false events and the patterns of "good" events. One of the authors, Paul Mazaika, was able to be both knowledge engineer and domain expert, which greatly facilitated knowledge acquisition. He interacted with other experts to develop rules which cover the hardware, software, and phenomenology aspects of making a decision regarding a possible event.

The scope of the knowledge base includes the functioning of the hardware, both in known correct states and in possibly erroneous states, the current configuration of the adaptive software, and the possibility of phenomenological sources causing spurious noise and clutter. This knowledge is "static" in the sense that the rules do not change during the analysis done by the expert system of a given case. The order and selection of rules may vary, but the set of rules in the knowledge base are constant. However, as the knowledge base is first being written and as it goes through an evolution until it reaches a mature form, the set of rules will be created and modified. The knowledge base may be developing even when the expert system is in full operation as additional information is found to be relevent or present information is reevaluated.

The rules in the knowledge base are structured as if-then-else clauses,

```
i.e.    IF condition(s)
        THEN consequence
        ELSE consequence
```

There may be numerous conditions leading to a single consequence. The conditions may be combined by using "and", "or", or "not". If the conditions evaluate to true the "then" consequence is asserted; if they are false the "else" consequence will be asserted. For example:

```
If the event is in a mountainous area and
   the event is in local daylight
Then a known phenomenology source is near the event
Else reflections from the mountains are not the cause.
```

If the two conditions are true, the fact that a phenomenology source is nearby will be asserted and made available for use as a condition in other rules. Similarly, if the conditions evaluate to false, which will happen if either one or both of the condition clauses are false, then the "else" clause that the event is not caused by reflections from the mountains will be asserted.

Since information about the satellite sensors, the phenomenology, and the event is rarely known with 100% certainty, each assertion is weighted by a confidence level.

likelihood	internal truth-confidence
very likely	true with high confidence
somewhat likely	true with medium confidence
very unlikely	false with high confidence

The expert system was originally set up to handle an expanded set of likelihoods which includes the following.

likelihood	internal truth-confidence
unlikely	true with low confidence
somewhat unlikely	false with medium confidence
possibly unlikely	false with low confidence

These last few are not being used because of the significantly greater number of rules needed to handle this many possibilities, as well as the fact that the operator who uses the system interactively would have a harder time choosing from 6 possible likelihood states than from 3. Thus, we now have a 3-tiered logic.

The dynamic system knowledge is stored in an assertion table which is separate from the static knowledge base. It stores the current state of what is known by the expert system and has all the assertions about the satellite system and the results of the "implicit" calculations. The inference engine determines the state of knowledge by executing the rules in the knowledge base and then updating this table as new assertions are made.

2.3. INFERENCE ENGINE

The expert system is data driven. The rules are organized into a hierarchy of several levels. Each level contains rules whose conditions are the consequences of rules on a lower level. At this stage of development, the ordering of levels was done manually, covering 11 levels at present. However, in the future we will have the precedence determined automatically.

The lowest level is called "implicit", containing the data reduction routines which are automatically initiated once the satellite data tape is selected. These routines do pattern recognition tasks and analysis of the events and the other returns in their proximity. The results are returned to the main system and are stored in the assertion table. Representative calculations are:

1. solar geometry angles as a function of time
2. nearby noise sources
3. data clustering
4. distances to selected features of the terrain
5. satellite sensor problems such as strobe and ringer noise.

After the implicit level has been executed, subsequent levels apply the rules in the knowledge base to what is then known about the event, the satellite, and the event's environment, as recorded in the assertion table. This is done by the inference engine which drives the expert system, executing rules at each level. On the top level a decision on the validity of the event is made. For each level the inference engine goes through the following stages.

1. Select the next rule, sequentially going down the list of rules for the level being considered.
2. Determine if the rule has previously been evaluated. If it has, go to the first step and select another rule.
3. Decide whether there is enough information available to evaluate the rule. This is done in two passes through the rules on each level. The conditions of the rules are compared to assertions in the knowledge base to determine what the current state of knowledge is. On the first cycle through, if there is missing information we skip the rule and go on to the next. However, on the second cycle, missing information puts us into "interactive mode" where the expert system asks us about the assertion.
4. The next step is to evaluate the truth of the antecedent condition(s), setting the "then" conclusion to true if they evaluate to true and, if there is an "else" conclusion, setting that to true if the conditions evaluated to false.
5. The concluding assertion is stored in the assertion table, and all rules which reach this same conclusion are flagged so that they are not evaluated again.
6. Then the process starts again, selecting the next rule until all the rules on the level have been attempted; this is cycle 1. The second cycle through the rules captures those with missing information. After the second cycle, the next level is entered, until the highest level is reached.

2.4. INTERACTIVE MODE

As mentioned above, during the second cycle through the rules, when the expert system is ready to evaluate a rule for which the truth of the conditions is not known, interactive mode is entered. The following example is a question which must still be answered by the user as to the health of the satellite system and sensors.

```
>>> Is the satellite system functioning properly?
        truth value(true/false/unknown): t
        confidence level(high/medium/low/unknown): m
```

At present, the expert system must rely on experts to decide whether something has gone wrong. In the future, the expert system will have enough knowledge to answer most, if not all, of the questions. It is worth noting that it may be a valuable feature of the computer system to continue to ask the human expert to make certain evaluations which are beyond its scope and capabilities.

2.5. QUERY MODE

Besides interactive questioning of the user, this prototype has an explanation feature that allows a user to interrogate the system about the current state and about the logic flow (i.e., the rules used). This explanation feature is extremely useful in debugging the rule base, and in substantiating the credibility of the inference engine.

The query mode is able to trace the system operation in a step by step fashion in such a style that the logic flow of the system can be understood by a non-programmer. The program is able to inform the user in easily understood terms what it did and why it did it, thereby instilling confidence in its operation. This

also makes it easier for the user to see what enhancements are necessary to the rule-base.

When the truth of a condition is unknown the system will request information from the operator. At this time interactive mode is entered. To gain additional information about why the computer asked the user a question, or to find what capabilities for explanation the system has, the user may enter query mode by typing "?". The system then gives a menu of the options.

```
Truth Values      Confidence Levels     General
------------      -----------------     -------
true              high                  ? for help
false             medium                + for explain
unknown           low                   rule
                  unknown               search tables
```

A response of "+" to a system query will cause the system to give further explanations about what information is needed. A reason why it is relevant may be included. Typing "r" or "rule" will give the specific rule which the system was trying to evaluate when the system found it did not know the truth of a condition, thus necessitating the questioning of the user. The last option is to search the tables: the rule base, the value/assertion table, and the limit/threshold table. Typing an "s" or "search" gives this menu:

```
Would you like to see any of the following?
        1) rules                  a) by rule#
                                  b) by phrase
                                  c) explanation of rule# n
                                  d) by level
        2) values/assertions      a) by name/phrase
                                  b) explanation of value# n
        3) limits                 a) by name

Please enter selection or 0 to end:
```

While this is presently menu driven, we hope to convert this to a more natural interaction, i.e., closer to English, with the user typing "search" and the computer prompting the user for which table and what kind of information is desired. We have left the interactive capability limited, spending the major part of our effort on the technical and systems aspects of the "intelligent assistant".

Running concurrently with the expert system is a display screen which enables system users to visually monitor the data. The user is able to examine the patterns in the data in the context of the display, which has the data superimposed upon a map. This facilitates the detection of flaws or inadequacies in the logic of the computer system as well as those in the data or the sensors which measured the data. This display is also a convenient debugging aid for testing rules in the prototyping effort, and as a double check of relevant calculations.

2.6. STATUS

To write the expert system, we have used C on both a VAX 11/780 and an Apollo workstation. This decision makes interfacing to procedures which do intensive numeric calculations straightforward. C is presently fairly easy to port to other computers, especially micros and small computers, making the idea of a stand alone "intelligent assistant" more likely. That C is much faster than the typical Artificial Intelligence languages is a crucial factor in this time-critical application. With quick execution, debugging of the rule base and the software takes less time and is more comprehensive, since a fairly large number of cases may be run in a reasonable amount of time.

The rule base contains about 200 rules at present. This rule set covers most of the "typical" causes of false event reporting. We are currently adding rules to handle the infrequent and poorly understood cases. It is anticipated that the final rule base will contain 300-500 rules.

There are only two or three assertions, depending on which rules need to execute for a given set of data, which cause the system to enter "interactive mode", to query the user. The test cases which we have run yield a correct evaluation in 23 out of 27 cases, which is about an 85% accuracy. The knowledge base was built independent of these data sets, so this is a fair estimate of the performance of the system.

The speed with which the system ran is close to real time. Although the system has not been optimized to run quickly, the cpu time for a run for over 80% of the cases was under a minute, and all of them ran with a cpu time under 1.5 minutes.

2.7. CONCLUSIONS FOR THE PROTOTYPE SYSTEM

In conclusion, we find the expert system to be a viable approach to event discrimination. Despite the wide variety of data and the numerous ways in which that data must be manipulated, the expert system initiates the data reduction procedures, feeds the results into the assertion table, and does analysis of them in the inference engine via the knowledge base. The structure of an expert system, which has the knowledge base independent of the inference mechanism, greatly facilitates maintainability and growth. New knowledge may be added to the system without having to do any reprogramming. Additional numeric routines may be added simply by updating a table of procedure names. The knowledge base may also be modified or enlarged by making entries into the table containing the rules.

The final decision which the system reaches for a number of test cases is encouraging. The expert system determines the validity of events correctly with a success rate an order of magnitude better than the current signal processing software. And we are still in the feasibility stage with an immature knowledge base.

Since the knowledge base and expert system software are still growing, we expect to further improve the performance. We plan to run the system in the field as an "intelligent assistant" to evaluate the

knowledge base, to determine how complete it is, and to evaluate the performance of the system in terms of accuracy and speed.

3. A MODEL OF THE OPERATOR'S KNOWLEDGE

3.1. LOGIC FLOW

The expert system is data driven, meaning that it is the data which drives the flow through the rule base. The overall logic flow is shown in Figure 2, leading from input features on the bottom to the true/false decision at the top. Local clutter is estimated by known phenomenology sources, observed data on the mission display, and inferred data from the proximity of blanks.

These factors and the knowledge gained by viewing the event on a mission display give an understanding of the local background. Combining this with an evaluation of the reliability of the individual returns comprising the collected event and the noise level in the vicinity give a 'technical evaluation' of the event.

This evaluation, combined with the user's expectation of seeing a true event and knowledge about the health of the sensors, the satellite, and the on-board processing leads to the final decision.

In the diagram, some of the implicit features, i.e., parameters resulting from the implicit level calculations, are listed beneath the boxes which contain the assertion for which they are inputs. Following the diagram are listings of the implicit features and the rules in the knowledge base. The implicit level is considered to be level 1, so the expert system rules start with level 2. There are about 40 implicit features and 200 rules in all.

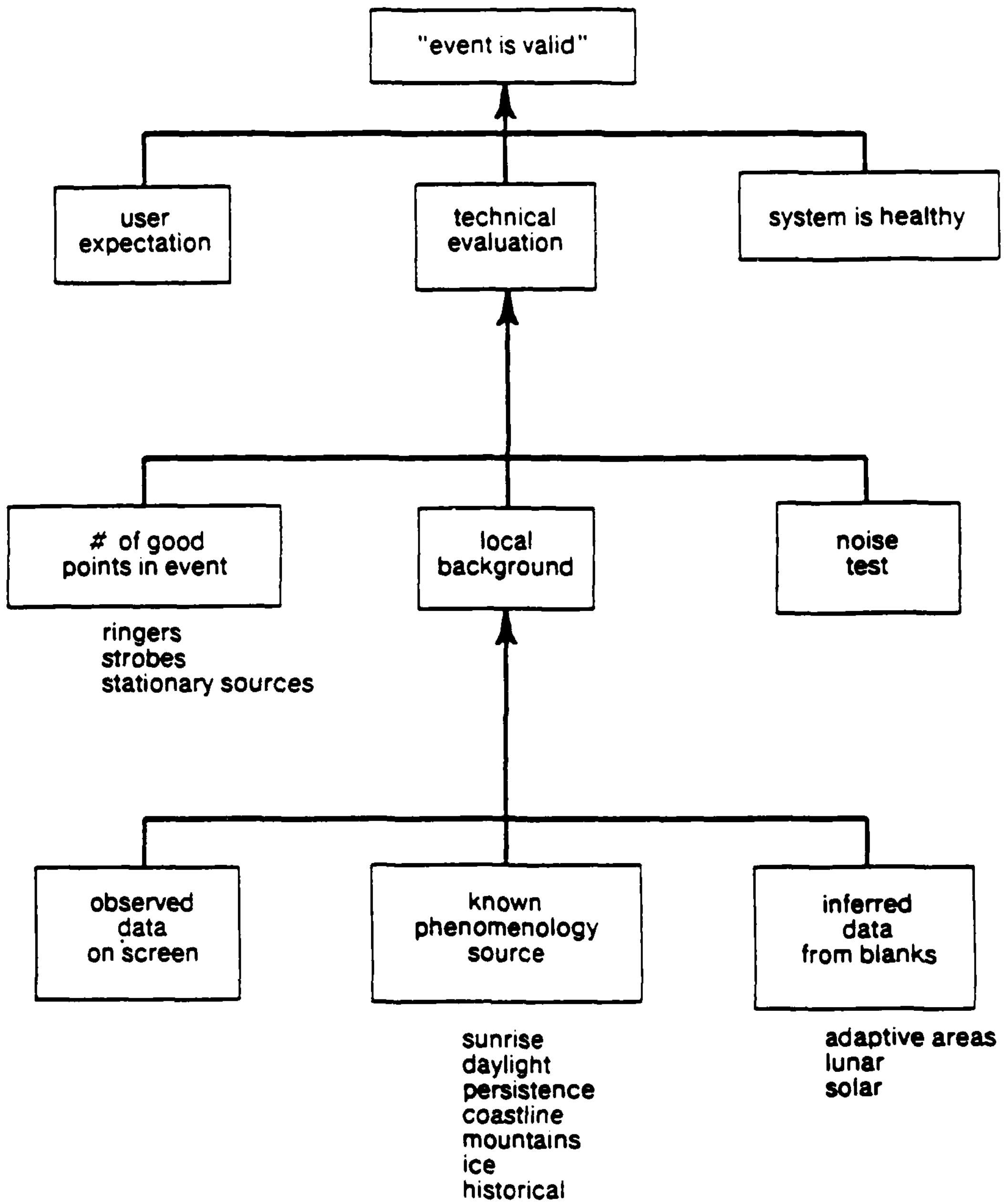

Figure 2. Basic Rule - Logic Flow

3.2. IMPLICIT LEVEL DATA REDUCTION

The first level of the expert system does data reduction. This is accomplished via a set of "implicit" routines, so designated because the calculations provide basic information about the state of the system without being explicitly developed by rules in the knowledge base. Only the numeric results of the calculations are available to the inference engine or the user in Query Mode.

The following is a list of the implicit knowledge being calculated:

1. distance to the horizon
2. distance to the coast
3. probability that the event is caused by noise
4. a flag whether the event is over land or sea
5. the maximum event intensity
6. a flag whether the intensity pattern is "reasonable"
7. distance to the terminator
8. distance to the terminator in 20 minutes
9. a flag whether the event is in a mountainous region
10. angular distance to the sun
11. the scattering angle
12. the specular point
13. local number of events
14. number of points passing stationary source test
15. number of points passing transient noise test
16. number of non-overshoot points
17. number of non-persisting returns
18. number of non-over-the-horizon points
19. number of non-event points in proximity
20. distance to the solar blank
21. distance to the lunar blank
22. distance to the closest high threshold adaptive area
23. distance to next closest high threshold adaptive area
24. a flag whether the solar blank is stationary
25. a flag whether the closest adaptive area blank is stationary
26. a flag whether the next closest adaptive area blank is stationary
27. a flag whether the lunar blank is stationary
28. the number of points revealed by a moving solar blank
29. the number of points revealed by a moving lunar blank

30. the number of points revealed by a changing closest adaptive area
31. the number of points revealed by a changing next closest adaptive area
32. a flag whether the event is in an Arctic ice region
33. a flag whether the event is in a region which has a history of background sources
34. the number of points in the collected event

The following is a list of the features that are not automatically calculated in the present version, rather they may be entered by the user. Usually only two inputs (expectation and functioning properly) are required from the user.

1. non-natural background
2. the expectation of an event
3. the system is functioning properly
4. attitude is the only error
5. the event is caused by a star (or celestial body)

3.3. KNOWLEDGE BASE

level 2

rule 104
If distance to horizon >= horizon threshold
Then the event is not close to the horizon [high conf]

This rule is used to separate out possible background sources.

rule 101
If probability that the event is caused by noise > max noise confidence threshold
Then the event is due to noise [high conf]

The noise thresholds are set so that 4 raw returns in the event imply the event is not noise, 3 raw returns imply the event might be noise, and 2 or fewer imply the event is noise. Adjacencies count as 2 raw returns. It would be better to take intensities into account, but this is not done.

rule 102
If probability that the event is caused by noise < min noise confidence threshold
Then the event is not due to noise [high conf]

The noise thresholds are set so that 4 raw returns in the event imply the event is not noise, 3 raw returns imply the event might be noise, and 2 or fewer imply the event is noise. Adjacencies count as 2 raw returns. It would be better to take intensities into account, but this is not done.

rule 103
If probability that the event is caused by noise >= min noise confidence threshold AND
probability that the event is caused by noise <= max noise confidence threshold
Then the event is due to noise [medium conf]

The noise thresholds are set so that 4 raw returns in the event imply the event is not noise, 3 raw returns imply the event might be noise, and 2 or fewer imply the event is noise. Adjacencies count as 2 raw returns. It would be better to take intensities into account, but this is not done.

rule 105
If the origin of the event = land
Then the event is over the land [high conf]
Else the event is over the sea [high conf]

If the event is close to a coastline, the land/sea decision could be in error.

rule 112
If the origin of the event = land
Then the event is over the land [high conf]
Else the event is not over the land [high conf]

If the event is close to a coastline, the land/sea decision could be in error.

rule 106
If the intensity pattern > profile fit threshold
Then the intensity profile is reasonable [high conf]

Allowable profiles either have a single hump, or the last intensity is the highest. Logic is for three point events only.

rule 107
If the intensity pattern < profile fit threshold
Then the intensity profile is not reasonable [high conf]

Allowable profiles either have a single hump, or the last intensity is the highest. Logic is for three point events only.

rule 109
If the event intensity < intensity threshold
Then the event intensity is less than 200 [high conf]
Else the event intensity is not less than 200 [high conf]

The event's intensity will rule out certain background sources.

rule 113
If the region is mountainous = mountainous region
Then the event is in a mountainous area [high conf]
Else the event is not in a mountainous area [high conf]

The mountainous regions are roughly defined by a 100 point world-wide data base.

rule 114
If distance to terminator < near terminator max AND
distance to terminator > near terminator min
Then the event is near the terminator [high conf]

Distance to terminator is used to estimate how close an event is to being sunlit.

rule 115
If distance to terminator > near terminator max AND
distance to terminator < far terminator max
Then the event is near the terminator [medium conf]

Distance to terminator is used to estimate how close an event is to being sunlit.

rule 116
If distance to terminator > far terminator max
Then the event is not near the terminator [high conf]

Distance to terminator is used to estimate how close an event is to being sunlit.

rule 117
If distance to terminator < far terminator min
Then the event is not near the terminator [high conf]

Distance to terminator is used to estimate how close an event is to

being sunlit.

rule 118
If distance to terminator < near terminator min AND
distance to terminator > far terminator min
Then the event is near the terminator [medium conf]

Distance to terminator is used to estimate how close an event is to being sunlit.

rule 119
If angular distance to sun < telescope angular width
Then the sun is in the telescope's field-of-view [high conf]

The sun diameter is 1/2 degree, the telescope diameter is taken as 9 degrees. If the sun center is within approximately 5 degrees of the telescope axis, then is directly in the telescope field-of-view.

rule 120
If angular distance to sun > optical off-axis max angle
Then the sun is not in the telescope's field-of-view [high conf]

The sun should not be a problem unless there is an anomaly in the telescope.

rule 121
If angular distance to sun >= telescope angular width AND
angular distance to sun <= optical off-axis max angle
Then the sun is in the telescope's field-of-view [medium conf]

When the sun is close to the field-of-view, diffraction and internal scattering can cause spurious data. The limits of 5 degrees to 10 degrees are a guess for the bounds of the optical off-axis rejection function.

rule 122
If scattering angle <= min scattering angle
Then the scattering angle is unfavorable [high conf]

Values from S.J. Young report. SAMSO TR-78-178.

rule 123
If scattering angle > min scattering angle AND
scattering angle < max scattering angle
Then the scattering angle is unfavorable [medium conf]

Values from S.J. Young report. SAMSO TR-78-178.

rule 124
If scattering angle >= max scattering angle
Then the scattering angle is not unfavorable [high conf]

Values from S.J. Young report. SAMSO TR-78-178.

rule 125
If specular point < min specular refl angle
Then the reflection geometry is unfavorable [high conf]

The BiReflectional Distribution Function tells the distribution of energy reflected in the specular direction. The estimate used here us that most energy is within 5 degrees and some energy is within 20 degrees.

rule 126
If specular point >= min specular refl angle AND
specular point <= max specular refl angle
Then the reflection geometry is unfavorable [medium conf]

The BiReflectional Distribution Function tells the distribution of energy reflected in the specular direction. The estimate used here us that most energy is within 5 degrees and some energy is within 20 degrees.

rule 127
If specular point > max specular refl angle
Then the reflection geometry is not unfavorable [high conf]

The BiReflectional Distribution Function tells the distribution of energy reflected in the specular direction. The estimate used here us that most energy is within 5 degrees and some energy is within 20 degrees.

rule 128
If number of points passing stationary source test <= low stationary source threshold
Then event is not free of stationary sources [high conf]

rule 129
If number of points passing stationary source test >= high stationary source threshold
Then event is free of stationary sources [high conf]

rule 130
If number of points passing stationary source test > low stationary source threshold AND
number of points passing stationary source test < high stationary source threshold
Then event is free of stationary sources [medium conf]

rule 131
If number of points passing transient noise test <= low transient noise threshold
Then event is not free of transient noise bursts [high conf]

rule 132
If number of points passing transient noise test >= high transient noise threshold
Then event is free of transient noise bursts [high conf]

rule 133
If number of points passing transient noise test > low transient noise threshold AND
number of points passing transient noise test < high transient noise threshold
Then event is free of transient noise bursts [medium conf]

rule 134
If number of non-overshoot points >= three
Then the event is not overshoot data [high conf]

rule 135
If number of non-overshoot points = two
Then the event is overshoot data [medium conf]

rule 136
If number of non-overshoot points < two

Then the event is overshoot data [high conf]

rule 137
If number of non-persisting returns >= three
Then the data is not due to persistence [high conf]

rule 138
If number of non-persisting returns = two
Then the data is due to persistence [medium conf]

rule 139
If number of non-persisting returns < two
Then the data is due to persistence [high conf]

rule 140
If stationary solar blank = zero
Then the solar blank is not stationary for the event duration [high conf]
Else the solar blank is stationary for the event duration [high conf]

rule 141
If stationary lunar blank = zero
Then the lunar blank is not stationary for the event duration [high conf]
Else the lunar blank is stationary for the event duration [high conf]

rule 159
If stationary closest adaptive area blank = zero
Then the closest high threshold adaptive area is not stationary [high conf]
Else the closest high threshold adaptive area is stationary [high conf]

rule 160
If stationary next closest adaptive area blank = zero
Then the next closest high threshold adaptive area is not stationary [high conf]
Else the next closest high threshold adaptive area is stationary [high conf]

rule 142
If the number of points in the collected event >= five AND
number of non-event points in proximity >= thirty-five
Then there is significant random clutter [high conf]

rule 143
If the number of points in the collected event >= five AND
number of non-event points in proximity >= ten
Then there is not significant random clutter [high conf]

rule 144
If the number of points in the collected event >= five AND
number of non-event points in proximity < thirty-five AND
number of non-event points in proximity > ten
Then there is significant random clutter [high conf]

rule 145
If the number of points in the collected event < five AND
number of non-event points in proximity > twenty
Then there is significant random clutter [high conf]

rule 146
If the number of points in the collected event < five AND

number of non-event points in proximity < six
Then there is not significant random clutter [high conf]

rule 147
If the number of points in the collected event < five AND
number of non-event points in proximity > six AND
number of non-event points in proximity <= twenty
Then there is significant random clutter [medium conf]

rule 148
If the event is in a historical background region > zero
Then some IR background is normally in this area [high conf]
Else some IR background is not normally in this area [high conf]

rule 152
If the region is Arctic ice > zero
Then the event is near Arctic ice [high conf]
Else the event is not near Arctic ice [high conf]

rule 157
If stationary closest adaptive area blank > zero
Then the closest high threshold adaptive area is stationary [high conf]
Else the closest high threshold adaptive area is not stationary [high conf]

rule 158
If stationary next closest adaptive area blank > zero
Then the next closest high threshold adaptive area is stationary [high conf]
Else the next closest high threshold adaptive area is not stationary [high conf]

rule 173
If points revealed by moving solar blank > one OR
points revealed by moving lunar blank > one OR
points revealed by changing closest adaptive area > one OR
points revealed by changing next closest adaptive area > one
Then suspected points are partially hidden by a blank [high conf]

rule 174
If points revealed by moving solar blank = zero AND
points revealed by moving lunar blank = zero AND
points revealed by changing closest adaptive area = zero AND
points revealed by changing next closest adaptive area = zero
Then suspected points are not partially hidden by a blank [high conf]

rule 175
If points revealed by moving solar blank > zero OR
points revealed by moving lunar blank > zero OR
points revealed by changing closest adaptive area > zero OR
points revealed by changing next closest adaptive area > zero
Then suspected points are partially hidden by a blank [medium conf]

level 3

rule 380
If there is an expectation of an event [high conf]
Then the event is expected [high conf]

If an event is specifically expected, the system gives more credibility to the events. Nonetheless, to ensure that all possible events are found, we take a conservative view that there is at least medium expectation of an event.

rule 110
  If distance to coast > map accuracy threshold AND
    the event is not close to the horizon [high conf]
  Then landsea decision is ok [high conf]

The accuracy of the DMA 13,000 point world map is about 30 km.

rule 111
  If distance to coast <= map accuracy threshold OR
    the event is close to the horizon [high conf]
  Then landsea decision is ok [medium conf]

The accuracy of the DMA 13,000 point world map is about 30 km.

rule 374
  If the event is not near the terminator [high conf]
  Then the event is not near local sunrise [high conf]

To determine if it is local sunrise, we see if there is more daylight 20 minutes later, and if it is close to the terminator.

rule 348
  If distance to terminator in 20 minutes < distance to terminator AND
    the event is near the terminator [high conf]
  Then the event is near local sunrise [high conf]

To determine if it is local sunrise, we see if there is more daylight 20 minutes later, and if it is close to the terminator.

rule 349
  If distance to terminator in 20 minutes < distance to terminator AND
    the event is near the terminator [medium conf]
  Then the event is near local sunrise [medium conf]

To determine if it is local sunrise, we see if there is more daylight 20 minutes later, and if it is close to the terminator.

rule 391
  If distance to terminator in 20 minutes >= distance to terminator
  Then the event is not near local sunrise [high conf]

To determine if it is local sunrise, we see if there is more daylight 20 minutes later, and if it is close to the terminator.

rule 392
  If distance to terminator > zero
  Then the event is in local daylight [high conf]

The event is computed to be in daylight by knowledge of the sun ephemeris and time of day.

rule 393

If distance to terminator <= zero AND
the event is near the terminator [high conf]
Then the event is in local daylight [high conf]

Clouds or mountains 4 miles high could be sunlit even if 160 miles from the terminator.

rule 394
If distance to terminator <= zero AND
the event is near the terminator [medium conf]
Then the event is in local daylight [medium conf]

An object or cloud has to be at least 15 or 20 miles above the earth to be sunlit.

rule 395
If distance to terminator <= zero AND
the event is not near the terminator [high conf]
Then the event is not in local daylight [high conf]

High clouds (30,000 - 50,000 ft) could be sunlit either directly or with atmospheric refraction at this distance from the terminator.

rule 386
If the event is over the land [high conf]
Then the event is not over the sea [high conf]

rule 340
If the event is not close to the horizon [high conf]
Then the moon is not near the event [high conf]

Only events near the horizon should be affected by this rule. For a star or planet, you should wait a few scans and check the motion.

rule 341
If the event is over the land [high conf] AND
landsea decision is ok [high conf]
Then the event is not wet [high conf]

rule 342
If the event is over the sea [high conf] AND
landsea decision is ok [high conf]
Then the event is wet [high conf]

rule 343
If landsea decision is ok [medium conf]
Then the event is wet [medium conf]

The computer is liable to make a region determination error in this case.

rule 405
If the scattering angle is not unfavorable [high conf]
Then the solar scatter is not a clutter source [high conf]

The scattering angle calculation does not account for whether it is local daylight.

rule 410
If the reflection geometry is not unfavorable [high conf]
Then the specular point is not near the event [high conf]

The reflection calculation does not account for local daylight.

rule 411
If event is free of stationary sources [high conf] AND
event is free of transient noise bursts [high conf]
Then there are enough clean points in the event [high conf]

rule 412
If event is not free of stationary sources [high conf] OR
event is not free of transient noise bursts [high conf]
Then there are not enough clean points in the event [high conf]

rule 413
If event is free of stationary sources [high conf] AND
event is free of transient noise bursts [medium conf]
Then there are enough clean points in the event [medium conf]

rule 414
If event is free of stationary sources [medium conf] AND
event is free of transient noise bursts [medium conf]
Then there are enough clean points in the event [medium conf]

rule 415
If event is free of stationary sources [medium conf] AND
event is free of transient noise bursts [high conf]
Then there are enough clean points in the event [medium conf]

rule 416
If the event is not overshoot data [high conf]
Then a concurrent event is not the cause [high conf]

rule 417
If the event is overshoot data [high conf]
Then a concurrent event is the cause [high conf]

rule 418
If the event is overshoot data [medium conf]
Then a concurrent event is the cause [medium conf]

rule 419
If the data is due to persistence [high conf]
Then an earlier event is the cause [high conf]

rule 420
If the data is not due to persistence [high conf]
Then an earlier event is not the cause [high conf]

rule 421
If the data is due to persistence [medium conf]
Then an earlier event is the cause [medium conf]

rule 367
If the event is close to the horizon [medium conf]

Then the event is not caused by a star (or celestial body) [high conf]

Stars are always above the horizon (as long as the attitude is good).

rule 368
If the event is not close to the horizon [high conf]
Then the event is not caused by a star (or celestial body) [high conf]

Stars are always above the horizon (as long as the attitude is good).

rule 371
If the event intensity is not less than 200 [high conf]
Then specular reflections is not the cause [high conf]

Specular reflections from the sea are not bright under normal atmospheric conditions.

rule 149
If some IR background is normally in this area [high conf]
Then background sources are historically in this area [high conf]

rule 150
If some IR background is not normally in this area [high conf] AND
the event is not close to the horizon [high conf]
Then background sources are not historically in this area [high conf]

rule 151
If some IR background is not normally in this area [high conf] AND
the event is close to the horizon [high conf]
Then background sources are historically in this area [medium conf]

rule 161
If distance to the solar blank < close blank distance AND
distance to the solar blank > very close blank distance AND
the solar blank is stationary for the event duration [high conf]
Then there is a static close solar blank [medium conf]

rule 162
If distance to the lunar blank < close blank distance AND
distance to the lunar blank > very close blank distance AND
the lunar blank is stationary for the event duration [high conf]
Then there is a static close lunar blank [medium conf]

rule 163
If distance to the closest high threshold adaptive area < close blank distance AND
distance to the closest high threshold adaptive area > very close blank distance AND
the closest high threshold adaptive area is stationary [high conf]
Then there is a static closest adaptive area [medium conf]

rule 164
If distance to next closest high threshold adaptive area < close blank distance AND
distance to next closest high threshold adaptive area > very close blank distance AND
the next closest high threshold adaptive area is stationary [high conf]
Then there is a static next closest adaptive area [medium conf]

rule 165
If distance to the solar blank < very close blank distance AND

the solar blank is stationary for the event duration [high conf]
Then there is a static close solar blank [high conf]

rule 166
If distance to the lunar blank < very close blank distance AND
the lunar blank is stationary for the event duration [high conf]
Then there is a static close lunar blank [high conf]

rule 167
If distance to the closest high threshold adaptive area < very close blank distance AND
the closest high threshold adaptive area is stationary [high conf]
Then there is a static closest adaptive area [high conf]

rule 168
If distance to next closest high threshold adaptive area < very close blank distance AND
the closest high threshold adaptive area is stationary [high conf]
Then there is a static next closest adaptive area [high conf]

rule 169
If distance to the solar blank > close blank distance OR
the solar blank is not stationary for the event duration [high conf]
Then there is not a static close solar blank [high conf]

rule 170
If distance to the lunar blank > close blank distance OR
the lunar blank is not stationary for the event duration [high conf]
Then there is not a static close lunar blank [high conf]

rule 171
If distance to the closest high threshold adaptive area > close blank distance OR
the closest high threshold adaptive area is not stationary [high conf]
Then there is not a static closest adaptive area [high conf]

rule 172
If distance to next closest high threshold adaptive area > close blank distance OR
the next closest high threshold adaptive area is not stationary [high conf]
Then there is not a static next closest adaptive area [high conf]

level 4

rule 352
If the event is caused by a star (or celestial body) [high conf]
Then a known phenomenology source is near the event [high conf]

Only events near the horizon should be affected by this rule. For a star or planet, you should wait a few scans and check the motion.

rule 382
If background sources are historically in this area [high conf]
Then a known phenomenology source is near the event [high conf]

rule 383
If background sources are historically in this area [medium conf]
Then a known phenomenology source is near the event [medium conf]

rule 384

If the neighboring data is a "known" non-natural background [high conf]
Then a known phenomenology source is near the event [high conf]

rule 385
If the neighboring data is a "known" non-natural background [medium conf]
Then a known phenomenology source is near the event [medium conf]

rule 363
If the event is near local sunrise [high conf]
Then a known phenomenology source is near the event [medium conf]

Local sunrise lights up the background in a few minutes time. This temporal variation sometimes causes false events.

rule 347
If the event is near local sunrise [medium conf]
Then a known phenomenology source is near the event [medium conf]

Local sunrise lights up the background in a few minutes time. This temporal variation sometimes causes false events.

rule 362
If the sun is in the telescope's field-of-view [high conf]
Then a known phenomenology source is near the event [high conf]

Possible internal optical reflections.

rule 366
If the sun is in the telescope's field-of-view [medium conf]
Then a known phenomenology source is near the event [medium conf]

Possible internal optical reflections.

rule 376
If the event is wet [high conf]
Then the event is not in a mountainous area [high conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 346
If the event is not in local daylight [high conf]
Then the solar scatter is not a clutter source [high conf]

This background can only occur from reflected sunlight.

rule 401
If the scattering angle is unfavorable [high conf] AND
the event is in local daylight [high conf]
Then the solar scatter is a clutter source [high conf]

The scattering angle calculation does not account for whether it is local daylight.

rule 402
If the scattering angle is unfavorable [high conf] AND
the event is in local daylight [medium conf]

Then the solar scatter is a clutter source [high conf]

The scattering angle calculation does not account for whether it is local daylight.

rule 403
If the scattering angle is unfavorable [medium conf] AND
the event is in local daylight [high conf]
Then the solar scatter is a clutter source [medium conf]

The scattering angle calculation does not account for whether it is local daylight.

rule 404
If the scattering angle is unfavorable [medium conf] AND
the event is in local daylight [medium conf]
Then the solar scatter is a clutter source [medium conf]

The scattering angle calculation does not account for whether it is local daylight.

rule 350
If the moon is near the event [high conf]
Then a known phenomenology source is near the event [medium conf]

The Moon or the lunar blank actually go slightly below the horizon because the moon is bright.

rule 351
If an earlier event is the cause [high conf] AND
the solar scatter is a clutter source [high conf]
Then a known phenomenology source is near the event [high conf]

Persistence.

rule 353
If an earlier event is the cause [high conf] AND
the solar scatter is a clutter source [medium conf]
Then a known phenomenology source is near the event [medium conf]

Persistence.

rule 423
If an earlier event is the cause [medium conf] AND
the solar scatter is a clutter source [medium conf]
Then a known phenomenology source is near the event [medium conf]

Persistence.

rule 424
If an earlier event is the cause [medium conf] AND
the solar scatter is a clutter source [high conf]
Then a known phenomenology source is near the event [medium conf]

Persistence.

rule 354

If a concurrent event is the cause [high conf]
Then a known phenomenology source is near the event [high conf]

Overshoot logic.

rule 422
If a concurrent event is the cause [medium conf]
Then a known phenomenology source is near the event [medium conf]

Overshoot logic.

rule 377
If the event is not in local daylight [high conf]
Then the specular point is not near the event [high conf]

Reflections from the sea must be close to the specular point to be bright, since the specular point is localized. This rule does not take into account that specular reflections from mountains could be quite far from the specular point.

rule 406
If the reflection geometry is unfavorable [high conf] AND
the event is in local daylight [high conf]
Then the specular point is near the event [high conf]

The reflection calculation does not account for local daylight.

rule 407
If the reflection geometry is unfavorable [high conf] AND
the event is in local daylight [medium conf]
Then the specular point is near the event [high conf]

The reflection calculation does not account for local daylight.

rule 408
If the reflection geometry is unfavorable [medium conf] AND
the event is in local daylight [high conf]
Then the specular point is near the event [medium conf]

The reflection calculation does not account for local daylight.

rule 409
If the reflection geometry is unfavorable [medium conf] AND
the event is in local daylight [medium conf]
Then the specular point is not near the event [high conf]

The reflection calculation does not account for local daylight.

rule 355
If the event is in a mountainous area [high conf] AND
the event is in local daylight [high conf]
Then a known phenomenology source is near the event [high conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 425

If the event is in a mountainous area [high conf] AND
the event is in local daylight [medium conf]
Then a known phenomenology source is near the event [medium conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 426
If the event is in a mountainous area [medium conf] AND
the event is in local daylight [medium conf]
Then a known phenomenology source is near the event [medium conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 356
If the solar scatter is a clutter source [high conf]
Then a known phenomenology source is near the event [medium conf]

Low angle scatter will only be a problem if there are high clouds. In general, we don't know the weather that well.

rule 357
If the solar scatter is a clutter source [medium conf]
Then a known phenomenology source is near the event [medium conf]

Low angle scatter will only be a problem if there are high clouds. In general, we don't know the weather that well.

rule 358
If the specular point is near the event [high conf] AND
the event intensity is less than 200 [high conf]
Then specular reflections is the cause [high conf]

Specular reflections from the sea are not bright under normal atmospheric conditions.

rule 369
If the specular point is not near the event [high conf]
Then specular reflections is not the cause [high conf]

Reflections from the sea must be close to the specular point to be bright, since the specular point is localized. This rule does not take into account that specular reflections from mountains could be quite far from the specular point.

rule 370
If the specular point is near the event [medium conf]
Then specular reflections is not the cause [high conf]

Reflections from the sea must be close to the specular point to be bright, since the specular point is localized. This rule does not take into account that specular reflections from mountains could be quite far from the specular point.

rule 359
If specular reflections is the cause [high conf] AND

the event is wet [high conf]
Then a known phenomenology source is near the event [high conf]

Rules 359-361 say that if the event is wet and specular reflections were present, then we know the background. Otherwise, we might know the background which could be a lake or river, for example.

rule 360
If specular reflections is the cause [high conf] AND
the event is wet [medium conf]
Then a known phenomenology source is near the event [medium conf]

Rules 359-361 say that if the event is wet and specular reflections were present, then we know the background. Otherwise, we might know the background which could be a lake or river, for example.

rule 361
If specular reflections is the cause [high conf] AND
the event is not wet [high conf]
Then a known phenomenology source is near the event [medium conf]

Rules 359-361 say that if the event is wet and specular reflections were present, then we know the background. Otherwise, we might know the background which could be a lake or river, for example.

rule 364
If the event is in a mountainous area [medium conf] AND
the event is in local daylight [high conf]
Then a known phenomenology source is near the event [medium conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 365
If the event is not in a mountainous area [high conf] AND
the event is in local daylight [high conf]
Then a known phenomenology source is near the event [medium conf]

High mountains and solar reflections off snow and ice cause background returns. Mountainous regions are defined by a 102 point data base.

rule 372
If the event is not in local daylight [high conf]
Then the specular point was not the cause [high conf]

This background can only occur from reflected sunlight.

rule 373
If the event is not in local daylight [high conf]
Then mountains are not the cause [high conf]

This background can only occur from reflected sunlight.

rule 378
If the event is not in a mountainous area [high conf]
Then mountains are not the cause [high conf]

This background can only occur from reflected sunlight.

rule 375
 If a concurrent event is not the cause [high conf] AND
  an earlier event is not the cause [high conf]
 Then other events are not the cause [high conf]

No overshoots or new phenomenology.

rule 177
 If there is not a static close solar blank [high conf] AND
  there is not a static close lunar blank [high conf] AND
  there is not a static closest adaptive area [high conf] AND
  there is not a static next closest adaptive area [high conf]
 Then there is not at least one close static blank [high conf]
 Else there is at least one close static blank [high conf]

rule 178
 If there is a static close solar blank [medium conf] AND
  there is a static close lunar blank [medium conf]
 Then there is more than one close static blank [high conf]

rule 179
 If there is a static close solar blank [medium conf] AND
  there is a static closest adaptive area [medium conf]
 Then there is more than one close static blank [high conf]

rule 180
 If there is a static close solar blank [medium conf] AND
  there is a static next closest adaptive area [medium conf]
 Then there is more than one close static blank [high conf]

rule 181
 If there is a static close lunar blank [medium conf] AND
  there is a static closest adaptive area [medium conf]
 Then there is more than one close static blank [high conf]

rule 182
 If there is a static close lunar blank [medium conf] AND
  there is a static next closest adaptive area [medium conf]
 Then there is more than one close static blank [high conf]

rule 183
 If there is a static closest adaptive area [medium conf] AND
  there is a static next closest adaptive area [medium conf]
 Then there is more than one close static blank [high conf]

rule 184
 If there is not a static close solar blank [high conf] AND
  there is not a static close lunar blank [high conf] AND
  there is not a static closest adaptive area [high conf]
 Then there is not more than one close static blank [high conf]

rule 185
 If there is not a static close solar blank [high conf] AND
  there is not a static close lunar blank [high conf] AND
  there is not a static next closest adaptive area [high conf]

Then there is not more than one close static blank [high conf]

rule 186
If there is not a static close solar blank [high conf] AND
there is not a static closest adaptive area [high conf] AND
there is not a static next closest adaptive area [high conf]
Then there is not more than one close static blank [high conf]

rule 187
If there is not a static close lunar blank [high conf] AND
there is not a static closest adaptive area [high conf] AND
there is not a static next closest adaptive area [high conf]
Then there is not more than one close static blank [high conf]

rule 176
If there is a static close solar blank [high conf] OR
there is a static close lunar blank [high conf] OR
there is a static closest adaptive area [high conf] OR
there is a static next closest adaptive area [high conf]
Then some static blank is very close [high conf]
Else some static blank is not very close [high conf]

level 5

rule 153
If the event is near Arctic ice [high conf] AND
the specular point is near the event [high conf]
Then a known phenomenology source is near the event [high conf]

rule 154
If the event is near Arctic ice [high conf] AND
the specular point is near the event [medium conf]
Then a known phenomenology source is near the event [medium conf]

rule 155
If the event is near Arctic ice [high conf] AND
the specular point is not near the event [high conf]
Then the Arctic ice is not a problem [high conf]

rule 156
If the event is not near Arctic ice [high conf]
Then the Arctic ice is not a problem [high conf]
Else the Arctic ice is a problem [high conf]

rule 188
If there is not more than one close static blank [high conf] AND
there is at least one close static blank [high conf]
Then there is exactly one close static blank [high conf]
Else there is not exactly one close static blank [high conf]

rule 189
If some static blank is very close [high conf] AND
number of non-event points in proximity >= one
Then a leaking static blank is likely [high conf]

rule 190

If there is more than one close static blank [high conf] AND
number of non-event points in proximity >= one
Then a leaking static blank is likely [high conf]

rule 191
If there is not at least one close static blank [high conf]
Then a leaking static blank is not likely [high conf]

rule 192
If some static blank is very close [high conf] AND
number of non-event points in proximity = zero AND
suspected points are partially hidden by a blank [high conf]
Then a leaking static blank is likely [high conf]

rule 193
If some static blank is very close [high conf] AND
number of non-event points in proximity = zero AND
suspected points are partially hidden by a blank [medium conf]
Then a leaking static blank is likely [high conf]

rule 194
If some static blank is very close [high conf] AND
number of non-event points in proximity = zero AND
suspected points are not partially hidden by a blank [high conf]
Then a leaking static blank is likely [medium conf]

rule 195
If there is more than one close static blank [high conf] AND
number of non-event points in proximity = zero AND
suspected points are partially hidden by a blank [high conf]
Then a leaking static blank is likely [high conf]

rule 196
If there is more than one close static blank [high conf] AND
number of non-event points in proximity = zero AND
suspected points are partially hidden by a blank [medium conf]
Then a leaking static blank is likely [high conf]

rule 197
If there is more than one close static blank [high conf] AND
number of non-event points in proximity = zero AND
suspected points are not partially hidden by a blank [high conf]
Then a leaking static blank is likely [medium conf]

level 6

rule 437
If the event is not near local sunrise [high conf] AND
the moon is not near the event [high conf] AND
the solar scatter is not a clutter source [high conf] AND
specular reflections is not the cause [high conf] AND
background sources are not historically in this area [high conf] AND
the neighboring data is not a "known" non-natural background [high conf] AND
the sun is not in the telescope's field-of-view [high conf] AND
other events are not the cause [high conf] AND
mountains are not the cause [high conf] AND

the Arctic ice is not a problem [high conf] AND
the event is not caused by a star (or celestial body) [high conf]
Then a known phenomenology source is not near the event [high conf]

rule 198
If there is exactly one close static blank [high conf] AND
some static blank is not very close [high conf] AND
suspected points are partially hidden by a blank [high conf]
Then a leaking static blank is likely [high conf]

rule 199
If there is exactly one close static blank [high conf] AND
some static blank is not very close [high conf] AND
suspected points are partially hidden by a blank [medium conf] AND
number of non-event points in proximity = one
Then a leaking static blank is likely [high conf]

rule 200
If there is exactly one close static blank [high conf] AND
some static blank is not very close [high conf] AND
suspected points are partially hidden by a blank [medium conf] AND
number of non-event points in proximity = zero
Then a leaking static blank is likely [medium conf]

rule 201
If there is exactly one close static blank [high conf] AND
some static blank is not very close [high conf] AND
suspected points are not partially hidden by a blank [high conf] AND
number of non-event points in proximity = one
Then a leaking static blank is likely [medium conf]

rule 202
If there is exactly one close static blank [high conf] AND
some static blank is not very close [high conf] AND
suspected points are not partially hidden by a blank [high conf] AND
number of non-event points in proximity = zero
Then a leaking static blank is not likely [high conf]

level 7

rule 203
If a leaking static blank is not likely [high conf] AND
there is significant random clutter [high conf]
Then observed data clusters are near the event [high conf]

rule 204
If a leaking static blank is not likely [high conf] AND
there is significant random clutter [medium conf]
Then observed data clusters are near the event [medium conf]

rule 205
If a leaking static blank is not likely [high conf] AND
there is not significant random clutter [high conf]
Then observed data clusters are not near the event [high conf]

rule 206

If a leaking static blank is likely [high conf] AND
there is significant random clutter [high conf]
Then observed data clusters are near the event [high conf]

rule 207
If a leaking static blank is likely [high conf] AND
there is significant random clutter [medium conf]
Then observed data clusters are near the event [high conf]

rule 208
If a leaking static blank is likely [high conf] AND
there is not significant random clutter [high conf]
Then observed data clusters are near the event [high conf]

rule 209
If a leaking static blank is likely [medium conf] AND
there is significant random clutter [high conf]
Then observed data clusters are near the event [high conf]

rule 210
If a leaking static blank is likely [medium conf] AND
there is significant random clutter [medium conf]
Then observed data clusters are near the event [high conf]

rule 211
If a leaking static blank is likely [medium conf] AND
there is not significant random clutter [high conf]
Then observed data clusters are near the event [medium conf]

level 8

rule 335
If observed data clusters are near the event [medium conf] AND
a known phenomenology source is near the event [high conf]
Then background clutter is present [high conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 336
If observed data clusters are near the event [medium conf] AND
a known phenomenology source is near the event [medium conf]
Then background clutter is present [medium conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 337
If observed data clusters are near the event [medium conf] AND
a known phenomenology source is not near the event [high conf]
Then background clutter is present [medium conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 338
If observed data clusters are not near the event [high conf] AND
a known phenomenology source is near the event [high conf]
Then background clutter is present [medium conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 339
If observed data clusters are not near the event [high conf] AND
a known phenomenology source is near the event [medium conf]
Then background clutter is present [medium conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 334
If observed data clusters are near the event [high conf] AND
a known phenomenology source is near the event [medium conf]
Then background clutter is present [high conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 332
If observed data clusters are near the event [high conf] AND
a known phenomenology source is not near the event [high conf]
Then background clutter is present [medium conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 331
If observed data clusters are near the event [high conf] AND
a known phenomenology source is near the event [high conf]
Then background clutter is present [high conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

rule 330
If observed data clusters are not near the event [high conf] AND

a known phenomenology source is not near the event [high conf]
Then background clutter is not present [high conf]

The collection of rules 330-339 combine the a priori knowledge of background with the observed background on the display to estimate the confidence that the event is due to background. Should add observed blanks to this logic.

level 9

rule 430
If there are enough clean points in the event [high conf] AND
background clutter is present [high conf]
Then the event is due to background [medium conf]

rule 431
If there are enough clean points in the event [high conf] AND
background clutter is present [medium conf]
Then the event is not due to background [high conf]

rule 432
If there are enough clean points in the event [high conf] AND
background clutter is not present [high conf]
Then the event is not due to background [high conf]

rule 433
If there are enough clean points in the event [medium conf] AND
background clutter is present [high conf]
Then the event is due to background [high conf]

rule 434
If there are enough clean points in the event [medium conf] AND
background clutter is present [medium conf]
Then the event is due to background [medium conf]

rule 435
If there are enough clean points in the event [medium conf] AND
background clutter is not present [high conf]
Then the event is due to background [medium conf]

rule 436
If there are not enough clean points in the event [high conf]
Then the event is due to background [high conf]

level 10

rule 379
If there is not an expectation of an event [low conf] OR
there is not an expectation of an event [medium conf] OR
there is not an expectation of an event [high conf] OR
there is an expectation of an event [low conf] OR
there is an expectation of an event [medium conf]
Then the event is expected [medium conf]

True-medium is normal alertness level. True-high is for tip-offs.

False-high is for very unexpected things such as wet events in land areas.

rule 381
If the system is functioning properly [high conf]
Then attitude is not the only suspected system error [high conf]

rule 387
If the system is functioning properly [medium conf]
Then attitude is the only suspected system error [medium conf]

rule 388
If the system is not functioning properly [high conf]
Then attitude is not the only suspected system error [high conf]

rule 324
If the event is due to background [medium conf] AND
the event is due to noise [medium conf]
Then the technical evaluation of the event is good [medium conf]

Rules 320-324 combine the noise and background knowledge into a technical evaluation of the event confidence.

rule 323
If the event is due to background [high conf] OR
the event is due to noise [high conf]
Then the technical evaluation of the event is not good [high conf]

Rules 320-324 combine the noise and background knowledge into a technical evaluation of the event confidence.

rule 322
If the event is due to background [medium conf] AND
the event is not due to noise [high conf]
Then the technical evaluation of the event is good [medium conf]

Rules 320-324 combine the noise and background knowledge into a technical evaluation of the event confidence.

rule 321
If the event is not due to background [high conf] AND
the event is due to noise [medium conf]
Then the technical evaluation of the event is good [medium conf]

Rules 320-324 combine the noise and background knowledge into a technical evaluation of the event confidence.

rule 320
If the event is not due to background [high conf] AND
the event is not due to noise [high conf]
Then the technical evaluation of the event is good [high conf]

Rules 320-324 combine the noise and background knowledge into a technical evaluation of the event confidence.

level 11

rule 315
If the system is not functioning properly [high conf] AND
attitude is the only suspected system error [medium conf] AND
the event is expected [high conf] AND
the technical evaluation of the event is not good [high conf]
Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 314
If the system is not functioning properly [high conf] AND
attitude is the only suspected system error [medium conf] AND
the event is expected [medium conf] AND
the technical evaluation of the event is not good [high conf]
Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 313
If the system is not functioning properly [high conf] AND
attitude is the only suspected system error [medium conf] AND
the event is expected [medium conf] AND
the technical evaluation of the event is good [medium conf]
Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 312
If the system is not functioning properly [high conf] AND
attitude is the only suspected system error [medium conf] AND
the event is expected [medium conf] AND
the technical evaluation of the event is good [high conf]
Then the event is valid [medium conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 311
If the system is not functioning properly [high conf] AND
attitude is the only suspected system error [medium conf] AND
the event is expected [high conf] AND
the technical evaluation of the event is good [high conf]
Then the event is valid [medium conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 310
  If the system is not functioning properly [high conf] AND
    attitude is the only suspected system error [medium conf] AND
    the event is expected [high conf] AND
    the technical evaluation of the event is good [medium conf]
  Then the event is valid [medium conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 309
  If the system is not functioning properly [high conf] AND
    attitude is the only suspected system error [high conf] AND
    the intensity profile is not reasonable [high conf]
  Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 308
  If the system is not functioning properly [high conf] AND
    attitude is the only suspected system error [high conf] AND
    the intensity profile is reasonable [high conf] AND
    the event is expected [medium conf]
  Then the event is valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 307
  If the system is not functioning properly [high conf] AND
    attitude is the only suspected system error [high conf] AND
    the intensity profile is reasonable [high conf] AND
    the event is expected [high conf]
  Then the event is valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 306
  If the system is functioning properly [high conf] AND
    the technical evaluation of the event is not good [high conf] AND
    the event is expected [high conf]
  Then the event is valid [medium conf]

This is a judgement rule based on expectation and technical evaluation.

rule 305
If the system is functioning properly [high conf] AND
the technical evaluation of the event is not good [high conf] AND
the event is expected [medium conf]
Then the event is not valid [high conf]

This is a judgement rule based on expectation and technical evaluation.

rule 304
If the system is functioning properly [high conf] AND
the technical evaluation of the event is good [medium conf] AND
the event is expected [medium conf]
Then the event is valid [medium conf]

This is a judgement rule based on expectation and technical evaluation.

rule 301
If the system is functioning properly [high conf] AND
the event is expected [medium conf] AND
the technical evaluation of the event is good [high conf]
Then the event is valid [high conf]

This is a judgement rule based on expectation and technical evaluation.

rule 302
If the system is functioning properly [high conf] AND
the event is expected [high conf] AND
the technical evaluation of the event is good [medium conf]
Then the event is valid [high conf]

This is a judgement rule based on expectation and technical evaluation.

rule 303
If the system is functioning properly [high conf] AND
the event is expected [high conf] AND
the technical evaluation of the event is good [high conf]
Then the event is valid [high conf]

This is a judgement rule based on expectation and technical evaluation.

rule 317
If the event is not expected [high conf] AND
the system is not functioning properly [high conf]
Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 316
If the event is not expected [high conf] AND
the technical evaluation of the event is good [high conf] AND
the system is functioning properly [high conf]
Then the event is valid [medium conf]

Very unexpected events are rejected unless everything else looks great.

rule 318
  If the event is not expected [high conf] AND
    the technical evaluation of the event is good [high conf] AND
    the system is functioning properly [medium conf]
  Then the event is valid [medium conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 319
  If the event is not expected [high conf] AND
    the technical evaluation of the event is good [medium conf] AND
    the system is functioning properly [medium conf]
  Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 325
  If the event is not expected [high conf] AND
    the technical evaluation of the event is not good [high conf] AND
    the system is functioning properly [medium conf]
  Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 326
  If the event is not expected [high conf] AND
    the technical evaluation of the event is good [medium conf] AND
    the system is functioning properly [high conf]
  Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

rule 327
  If the event is not expected [high conf] AND
    the technical evaluation of the event is not good [high conf] AND
    the system is functioning properly [high conf]
  Then the event is not valid [high conf]

If the system is not functioning properly, we try to find out if only the attitude is bad. If this is the case, and the intensity profile is OK, the event is probably OK even if its motion is poor. If there are other problems, we lower our confidence in the event.

4. IMPLEMENTATION DETAILS

4.1. TABLES

The expert system is largely table-driven, which is a software engineering feature used for clarity both in the expert system's organization as well as within the software. Here is a brief overview of what the tables are and where they come into play. A list of them follows:

```
Rules
Assertions
Limits
Remarks
Diagnostics
Implicit
```

4.1.1. Rules

The *rule table* is also known as the *knowledge base*. This is the repository for the human expert's knowledge about the domain, which in this case is how to determine whether data taken by a satellite 'matches' a paticular pattern. This we have termed *static* knowledge, in that the rules themselves do not change while the expert system is making an analysis.

4.1.2. Assertions

The *assertion table* contains *dynamic* knowledge. It has the assertions about the event, the satellite, or any relevent information. These are specific for each case being studied. During the execution of the expert system they will take on *values*, which will be either numeric,

```
eg. distance to the terminator = 100 km.,
```

or the values will be a truth value with a certain confidence level,

```
eg. The technical evaluation of the event is good [high conf].
```

4.1.3. Limits

The *limits table* has thresholds for use with the rule base. Rules may make numeric comparisons of the form:

```
If assertion-value comparison-operator threshold
Then assertion.
```

as in the following example:

```
If specular point < min specular refl angle
Then the reflection geometry is unfavorable.
```

4.1.4. Remarks

The *remark table* has comments about the rules and assertions. These remarks expand upon and explain the relevence of the information in the knowledge base and rule table. When the system queries the user for information, the user has the option to request an explanation about why the question was asked or for an amplification of what the assertion means. Although the remarks are stored in a separate table, they have been printed out in conjunction with the appropriate rules and assertions .

4.1.5. Diagnostics

The *diagnostics table* keeps track of physical information about the event, such as the event's location or how many points comprise the event. The table also has diagnostics about the state of the satellite-sensor-onboard processing system. If a blank was leaking, a message to that effect would be written here. The aim of the diagnostics table is to provide the user quick access to information determining the health of the system which has collected, measured and analyzed the event.

4.1.6. Implicit

The *implicit table* is used by the implicit controller program to connect the data reduction procedures, called the implicit routines, with the main expert system. The controller, called from the main system, starts execution of the implicit routines named in the table. The results are then stored in the assertion table for use by the inferencing mechanism in evaluating the rules on successive levels of the knowledge base. The implicit level is the first or lowest level.

The expert system begins with initialization. The user is asked to select the date of the event to be validated. Then the knowledge for which the system is called an expert is read. This involves reading rules from the rule table or knowledge base, values and assertions from the assertion table, thresholds from the limits table, and comments about the rules or assertions from the remarks table. Figure 3 shows the initialization process. Once the tables have been read, a diagnostics table is created and then the implicit level controller is invoked.

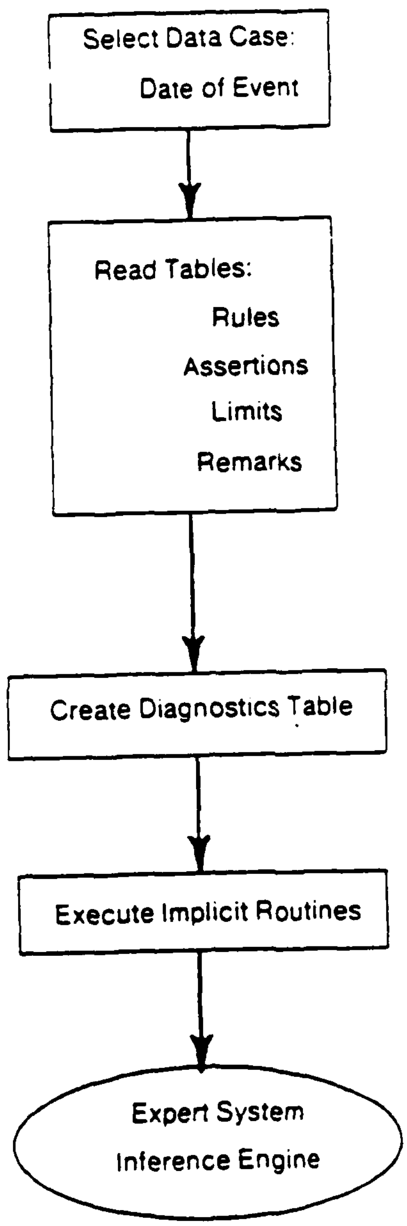

Figure 3. Initialization

4.2. IMPLICIT LEVEL OPERATION

Figure 4 shows how the implicit level fits into the expert system. The bold arrows show the main flow of command. The parts of the system represented by ellipses are to signify the course through the expert system, and are not part of the implicit level operation.

The implicit controller reads the implicit table which names the implicit routines to be run. Using a table achieves independence of these data reduction routines from the main inferencing system, facilitating the addition of new routines.

The controller starts execution of the data reduction routines reading the delog data and the world data bases to determine the environment which surrounds the event and the state of the sensors and on-board processing. The results are fed back to the controller which then stores the values in the assertion table. These assertions become the input features to the expert system. At the same time, any diagnostics reported by the routines are written to the diagnostics table. This latter table is an alarm log, pinpointing any key features the system has found. It is also used as a scratch pad to keep track of what has been determined about the event, such as the number of points and its location.

When all of the implicit routines have been executed, the implicit controller relinquishes control and the inference engine starts its course.

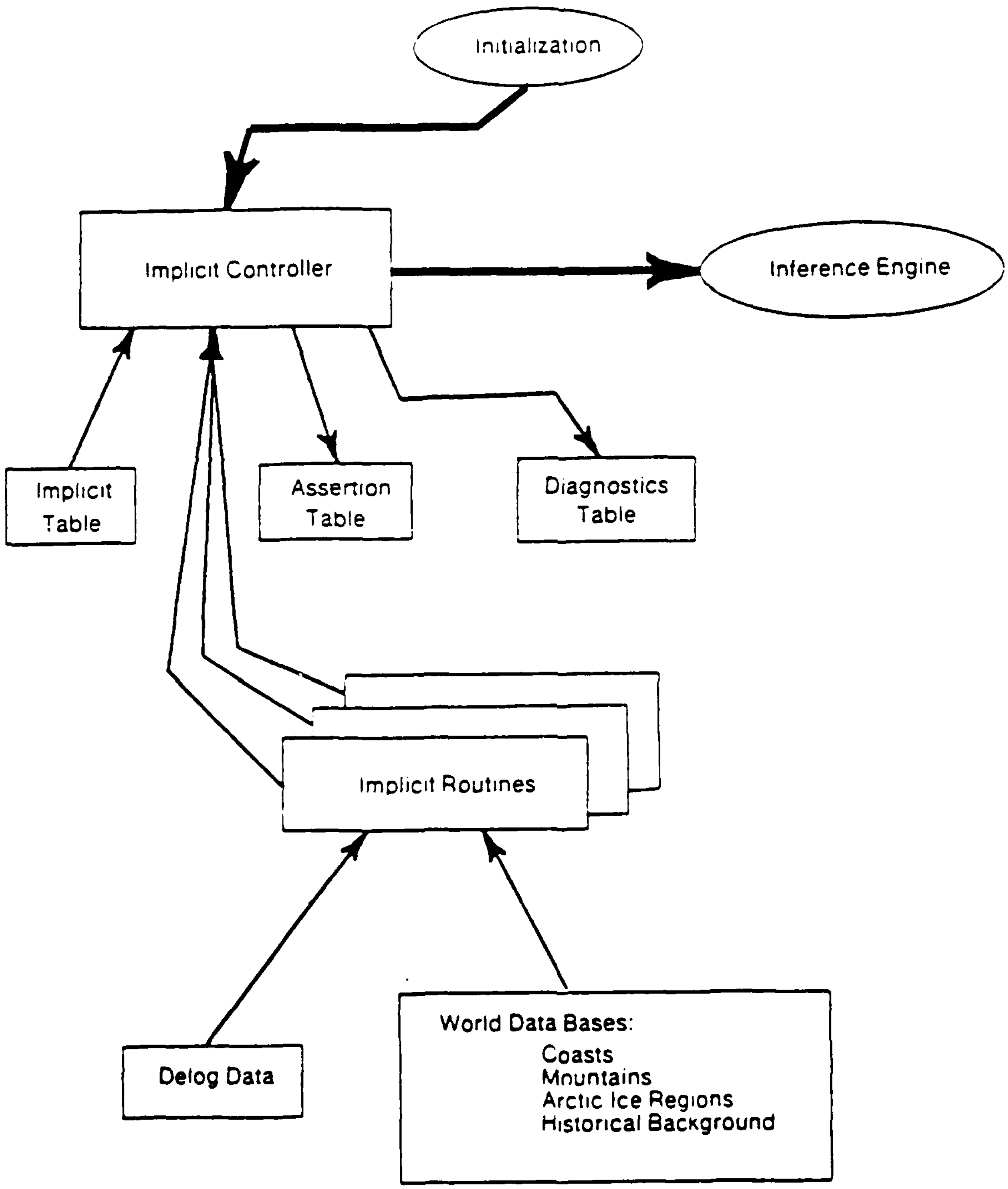

Figure 4. Implicit Level Data Reduction

4.3. ASSERTIONS

The following is a list of assertions and value names. The latter are mainly the results from the implicit calculations. Thus, "distance to horizon" might have a value of 100 km, whereas "the event is expected" would have a truth value and confidence level, "true with high confidence".

1. distance to horizon
2. probability that the event is caused by noise
3. the event origin
4. The event is over the land.
5. the event intensity
6. the origin of the event
7. the intensity pattern
8. The event is over the sea.
9. distance to terminator
10. distance to terminator in 20 minutes
11. the region is mountainous
12. angular distance to sun
13. scattering angle
14. specular point
15. local number of events

Within the same or a neighboring sector, within 2 minutes

16. number of points passing stationary source test

The stationary source tests look for two other points at the same location within two minutes.

17. number of points passing transient noise test

Ringers and strobes are included in transient noise.

18. Event is free of stationary sources.

19. Event is free of transient noise bursts.

20. number of non-overshoot points

21. number of non-persisting returns

22. number of non-over-the-horizon points

23. number of non-event points in proximity

24. The scattering angle is unfavorable.

25. The reflection geometry is unfavorable.

26. A leaking static blank is likely.

27. distance to the solar blank

Distance is measured to the boundary of the blank. Solar and lunar blank is at PCM 31. A distance of 10000 means the blank was non-existent.

28. distance to the lunar blank

Distance is measured to the boundary of the blank. Solar and lunar blank is at PCM 31. A distance of 10000 means the blank was non-existent.

29. distance to the closest high threshold adaptive area

30. distance to next closest high threshold adaptive area

31. stationary solar blank

32. distance to coast

33. stationary closest adaptive area blank

34. stationary next closest adaptive area blank

35. Landsea decision is ok.

36. The event is overshoot data.

37. The data is due to persistence.

38. stationary lunar blank

39. The closest high threshold adaptive area is stationary.

40. The next closest high threshold adaptive area is stationary.

41. points revealed by moving solar blank

These points are the number per scan within 50 arcsecs of the event whose threshold is above the second brightest event point.

42. points revealed by moving lunar blank

These points are the number per scan within 50 arcsecs of the event whose threshold is above the second brightest event point.

43. points revealed by changing closest adaptive area

These points are the number per scan within 50 arcsecs of the event whose threshold is above the second brightest event point.

44. points revealed by changing next closest adaptive area

These points are the number per scan within 50 arcsecs of the event whose threshold is above the second brightest event point.

45. the region is Arctic ice

46. the event is in a historical background region

47. Some IR background is normally in this area.

48. The event is near Arctic ice.

49. The Arctic ice is a problem.

50. Some static blank is very close.

51. There is more than one close static blank.

52. There is at least one close static blank.

53. There is exactly one close static blank.

54. the number of points in the collected event

55. There is a static close solar blank.

56. There is a static close lunar blank.

57. There is a static closest adaptive area.

58. There is a static next closest adaptive area.

59. Suspected points are partially hidden by a blank.

60. The system is functioning properly.

61. The technical evaluation of the event is good.

62. The event is expected.

63. There is an expectation of an event.

64. The solar blank is stationary for the event duration.

65. The lunar blank is stationary for the event duration.

66. Attitude is the only suspected system error.

67. The intensity profile is reasonable.

68. Background sources are historically in this area.

69. The neighboring data is a "known" non-natural background.

Mission B, for example.

70. There is significant random clutter.

71. Background clutter is present.

72. The event is due to background.

73. The event is due to noise.

74. A known phenomenology source is near the event.

75. Observed data clusters are near the event.

76. There are enough clean points in the event.

77. The event is close to the horizon.

78. The event is caused by a star (or celestial body).

79. The event is in a mountainous area.

80. The sun is in the telescope's field-of-view.

81. The moon is near the event.

82. The event is near the terminator.

83. The event is near local sunrise.

84. The event is in local daylight.

85. The sun is near the event.

86. An earlier event is the cause.

87. A concurrent event is the cause.

88. The solar scatter is a clutter source.

89. The specular point is near the event.

90. The event is wet.

91. The specular point was the cause.

92. Mountains are the cause.

93. Specular reflections is the cause.

94. Solar effects are the cause.

95. Miscellaneous effects are the cause.

96. Other events are the cause.

97. The event is valid.

98. The event intensity is less than 200.

4.4. THRESHOLDS TABLE

Some of the rules compare the values of assertions to thresholds or limits. The numerical values of the thresholds are stored in the Threshold Table which follows.

To Be Determined.

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4.5. GRAMMAR

The rules are written in a stylized format that is a compromise between being easy for the computer to interpret and easy to convert into an English sentence. The stylized format is the *grammar* of the rule base.

The rules are of two types. Their format may contain a numerical comparison, and hence a comparison operator, or they may test the values of assertion(s), possibly connected by "AND" or "OR". The first case would appear as:

```
IF A comparison-operator B
THEN C
[ELSE D]
```

where A is a value name, B is either a value name or a threshold and C is the conclusion. Allowable comparison operators include >=, <=, =, >, <, !=. "ELSE D" is optional. It is asserted if the antecedent is false. An example of this type of rule is:

```
IF angular distance to sun > optical off-axis max angle
THEN the sun is not in the telescope's field-of-view [high conf].
```

The second kind of rule

```
IF A [AND
   B AND
   C]
THEN D
[ELSE E]
```

The rule-interpretation subroutine determines the truth value of the conditions of the given rule, and interprets how they are connected (by AND, OR, or by a mathematical comparison operator). In the case of comparison, the objects being compared must be retrieved. There are two ways this can happen. If the comparison is of one assertion value with another assertion value, the inference engine seeks both values in the assertion table, whereas if the comparison is of an assertion value to a threshold, the threshold is retrieved from the limit table.

Once the truth value of each conditional assertion is known, then the truth value of the rule as a whole can be evaluated. The conditions are true only if the truth value and confidence level of each assertion is exactly met. If any assertion has an unassigned value, the rule will not be fired.

4.6. DATA FORMATS

A large variety of data was extracted from the recorded mission data in order to provide the required inputs to the expert system. This section lists the formats of the data input tables that were prepared for use by the implicit routines.

4.6.1. raw

```
gmt              seconds
lat              degrees
lon              degrees
azimuth          radians
elevation        radians
intensity
cell#
1.000
adjacencies
#cell responded
flag
```

4.6.2. event

```
origin time      seconds
satellite lat    degrees
satellite lon    degrees
phase time       seconds
delta gmt        seconds
event lat        degrees
event lon        degrees
intensity
flag
event azim       radians
event elev       radians
```

4.6.3. ephemeris

record 1

```
gmt                      seconds
dist to earth ctr        km
satellite subpt lat      radians
satellite subpt lon      radians
sun azimuth              radians
```

record 2

```
sun elevation            radians
specular pt az           radians
specular pt el           radians
eca horiz                radians
eca nadir                radians
```

4.6.4. blanks

solar & lunar blanks

gmt	seconds
left azimuth	radians
right azimuth	radians
lower elevation	radians
upper elevation	radians
solar or lunar flag	1 (= solar) or -1 (= lunar)

adapative area blanks

gmt	seconds
size	
threshold	
age	
density	
azimuth	radians
elevation	radians
status	
delta azimuth	arcsec
delta elevation	arcsec
distance to event	arcsec

4.6.5. rule.base

rule number
line# of rule or zero if simple rule
level
IF value#
comparison symbol (< > <= >= = !=)
threshold# starting with the letter "t" or value#
IF truth of IF value
IF confidence of IF value
conjunction (AND or OR)
THEN value#
THEN truth of THEN value
THEN confidence of THEN value
ELSE value#
ELSE truth of ELSE value
ELSE confidence of ELSE value
rule category (phenomenology, sensor, etc.) - not used
remark#

4.6.6. value.tbl

value#
value name/assertion
value
rule# or program
truth
confidence
level#
remark#

4.6.7. thresh.tbl

```
limit#
name
value
units
```

4.6.8. remark.tbl

```
remark#
comments
```

4.6.9. implicit.tbl

```
procedure
value#
```

END
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MARCH, 1988
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